ARMY RESEARCH LABORATORY

Preliminary Study of Electronic Replacement Compasses for the Army

by Bruce R. Geil

ARL-MR-223

November 1995

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
November 1995

3. REPORT TYPE AND DATES COVERED
Final, from Sept. 1993–Sept. 1994

4. TITLE AND SUBTITLE
Preliminary Study of Electronic Replacement Compasses for the Army

5. FUNDING NUMBERS

6. AUTHOR(S)
Bruce R. Geil

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
Attn: AMSRL-WT-NG
2800 Powder Mill Road
Adelphi, MD 20783-1197

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-MR-223

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Test Measurement and Diagnostic Equipment Activity
Attn: AMSMI-TMDE-DR
10115 Duportail Rd, Ste 136
Ft. Belvoir, VA 22060-5847

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Army Research Laboratory (ARL) at Adelphi, MD, along with the U.S. Army Test Measurement and Diagnostic Equipment Activity of Fort Belvoir, VA, has studied electronic replacements for the standard issue lensatic compass. We studied the KVH DataScope, the KVH C-100 compass engine, and the Casio Pathfinder digital watch/compass. Several tests were run on each compass to determine its suitability as a replacement for the lensatic compass. We conclude that an electronic compass will be more accurate and useful for the soldier.

14. SUBJECT TERMS
Electronic, compass

15. NUMBER OF PAGES
18

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

Contents

Figures

Tables

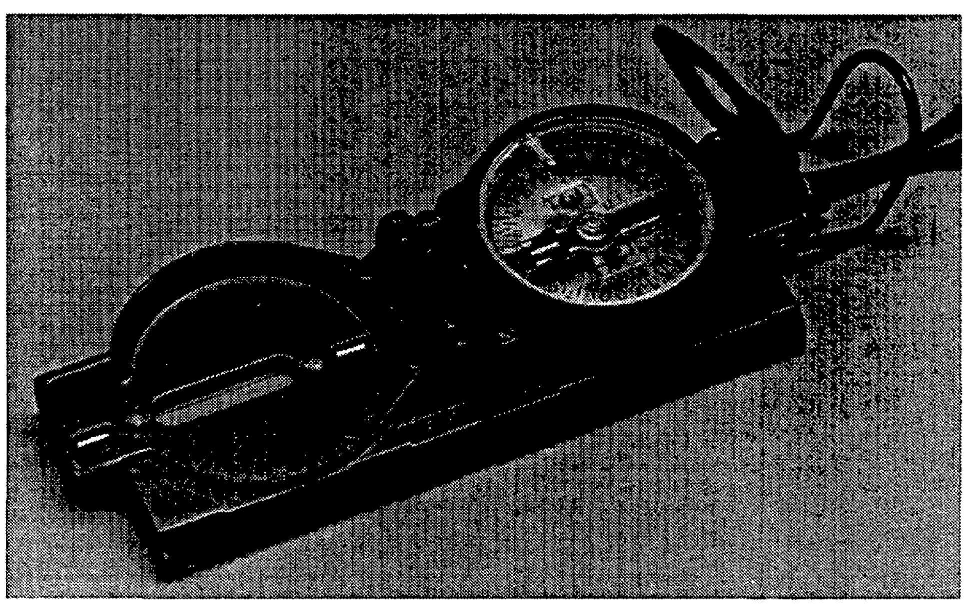
Page intentionally blank

1. Introduction

The Army Research Laboratory (ARL) in Adelphi, MD, and the U.S. Army Test Measurement and Diagnostic Equipment Activity of Fort Belvoir, VA, have been working to find a replacement compass for the standard-issue Army lensatic compass. The program involved looking into the concept of identifying a nondevelopmental item (NDI) (i.e., off-the-shelf) compass to replace the fielded lensatic compass. The lensatic compass is illuminated by small tritium vials that (1) deplete quickly and (2) must be disposed of as hazardous waste. The worn-out compasses must be returned to a central depot (in Ft. Belvoir), where they are disposed of as hazardous waste at considerable Army expense. This program is looking into the use of off-the-shelf, or slightly modified, commercial electronic compasses to solve these two critical problems. Preliminary studies on custom-fabricated electronic compasses are also being conducted, in case none of the commercial compasses meets the Army's requirements.

Since before World War II, the U.S. Army has used the same basic lensatic compass (see fig. 1). An advantage of this compass is its very simple construction, with very few moving parts. A major problem for the Army is the compass' night illumination material. The modern lensatic compass uses tritium to illuminate the compass. Tritium is radioactive and decays after about three years to the point that it does not effectively illuminate the compass. When the tritium decays to this point, the entire compass must be disposed of as low-level radioactive waste. The cost of the disposal is almost as high as the cost of the compass itself. In addition, the company that makes these compasses has indicated that they cannot replace the depleted tritium tubes. Another major disadvantage of the present compass is that it cannot be interfaced with the new electronic mapping systems being developed for the Army under the digital battlefield program.

Figure 1. Lensatic compass.

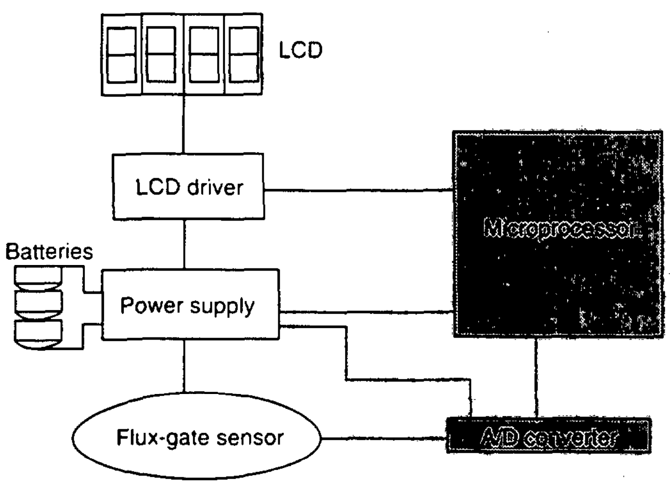


There are several possible solutions to the present lensatic compass problems, some of which include modifications to the present compass. But another solution would be to purchase an NDI compass off the shelf as a replacement. If no off-the-shelf NDI compass meets all of the requirements, it should be possible to work with the manufacturer to create a compass design that will meet the Army's requirements, while still reducing the cost of the present compass. A final option would be to design and build a new hand-held compass that will meet all Department of Defense (DoD) specifications; but, given the large numbers of NDI electronic compasses available, this is clearly a last resort.

2. Design

All of the electronic compasses tested for this program have six major components. A schematic of these components is shown in figure 2. The main component is the flux-gate magnetometer. This sensor measures the earth's magnetic field using a saturable ferrite ring core. The magnetometer mechanically floats in a fluid-filled plastic housing, and is driven into saturation by electrical coils located outside of the plastic housing using an ac field. Two additional windings measure the amplitude of the pulses generated by the earth's magnetic flux.[1-3] These data are converted to digital form using an analog-to-digital (A/D) converter and then sent to a microprocessor. The A/D converters used in these compasses are either 8- or 10-bit accuracy. The data from the A/D converter are filtered and averaged in the microprocessor, and the compass bearing is calculated. The directional bearing value is then sent to the liquid crystal display (LCD) driver, which in turn drives an LCD. All of the compasses studied have back-lit LCDs to make night operation possible. Each compass also has a power module consisting of a battery supply, power conditioning, and a signal generator to drive the flux-gate sensor.

Figure 2. Schematic of standard electronic compass.



[1]*KVH DataScope C-100 compass engine data package.*
[2]*Timothy J. Peters, "Automotive Navigation Using a Magnetic Flux-Gate Compass," IEEE Transactions on Vehicular Technology, VT-35, No. 2, pp. 41–47, May 1986.*
[3]*Paul Horowitz and Winfield Hall, The Art of Electronics, Cambridge University Press, p. 1007, 1989.*

Figure 3 is a photograph of the Casio Pathfinder compass/watch. The component in the middle houses the compass electronics. The LCD display is shown at the lower left and the power module in the lower right. Figure 4 is a photograph of the flux-gate magnetometer at the bottom with the A/D converter and filtering elements located directly above the flux-gate sensor. The magnetometer in the DataScope is larger than the one in the Pathfinder, but is more accurate. Figure 5 shows the other side of the electronics module, with the epoxy-encased microprocessor in the middle and the LCD connections at both edges. In the Pathfinder, the microprocessor also handles the watch functions, while in the DataScope the microprocessor handles the range finding, unit conversions, and time keeping. Figure 6 is a closeup of the flux-gate magnetometer, detailing the windings that allow the system to sense the earth's magnetic field. The center section contains the ferrite ring core.

There are several advantages to using an all-electronic digital compass instead of the present lensatic compass. The electronic compass could be easily integrated into the digital battlefield. Through the use of the microprocessor, data points can be entered into the compass for future reference. This technique can also be used to store several points for triangulation and other orienteering tasks. Since the compass need only use a fraction of the microprocessor's capabilities, future upgrades will be easily accommodated. These upgrades could include built-in Global Positioning System (GPS) equipment, map generation, map measuring, or other types of systems. The electronic compass will also solve the hazardous waste disposal problem presented by the lensatic compass.

Figure 3. Cutaway of compass watch.

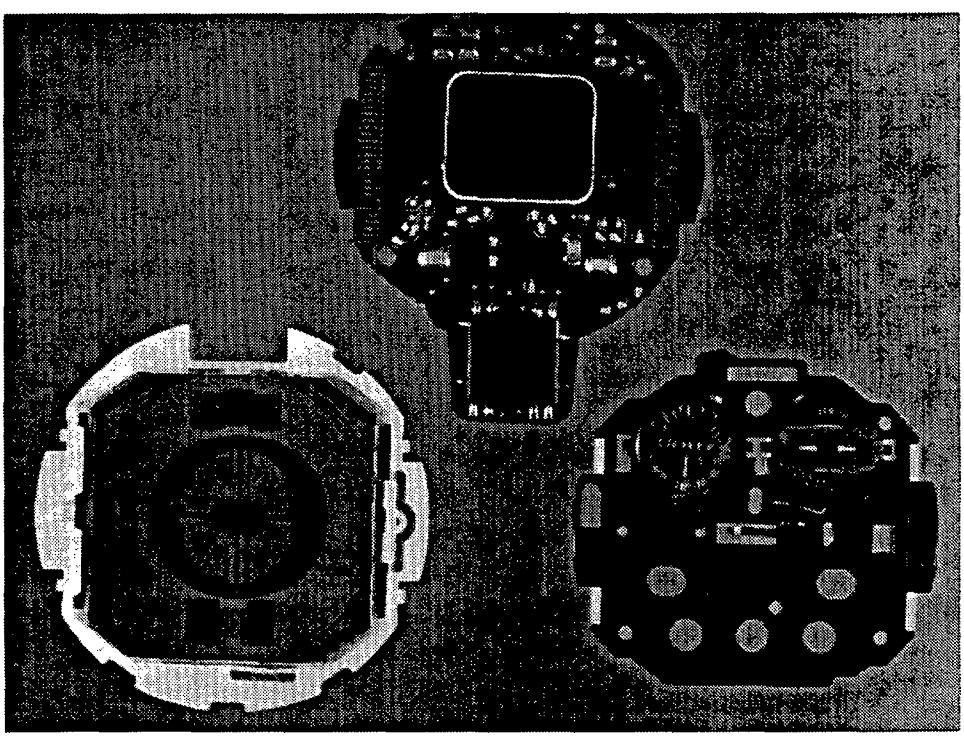


Figure 4. Closeup of electronic module.

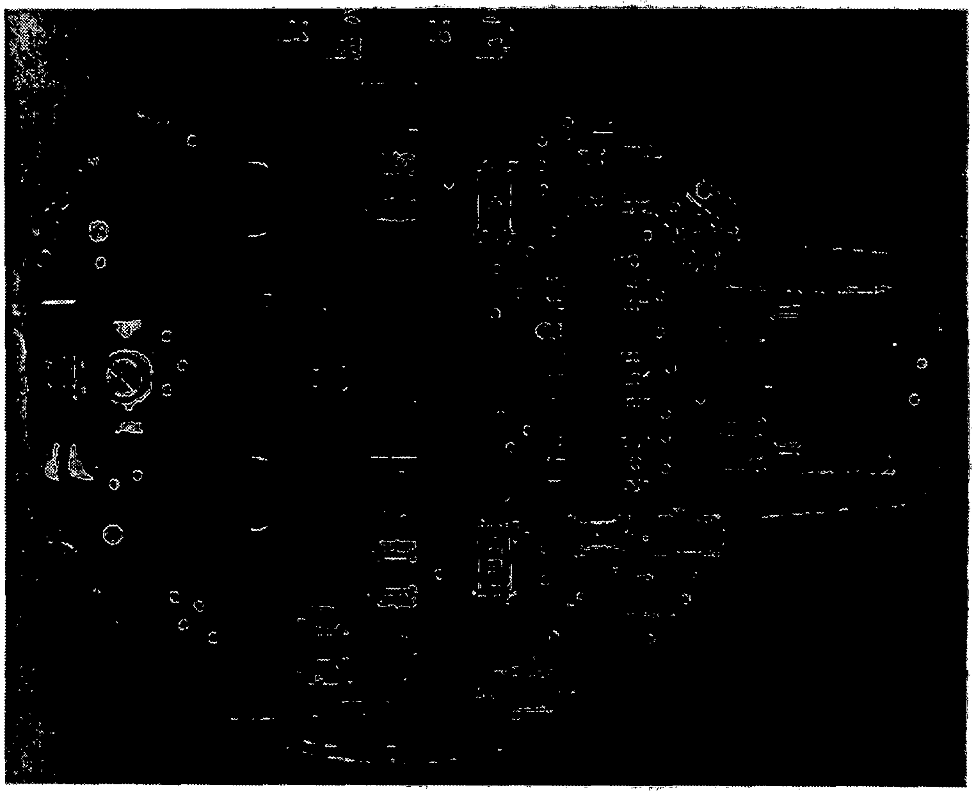


Figure 5. Back side of electronics module.

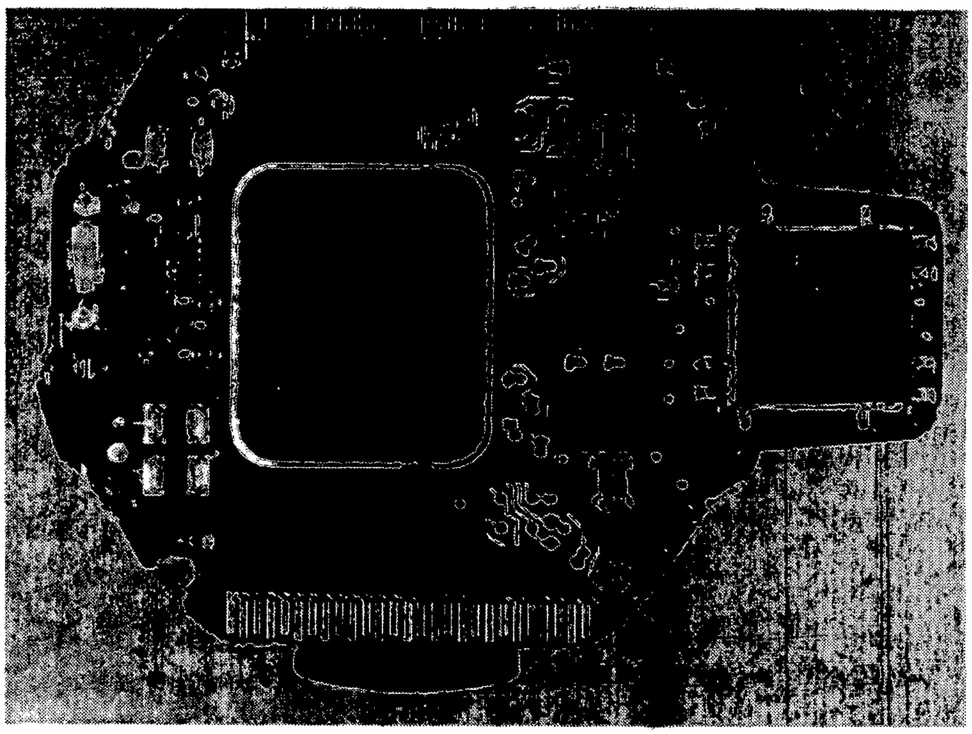
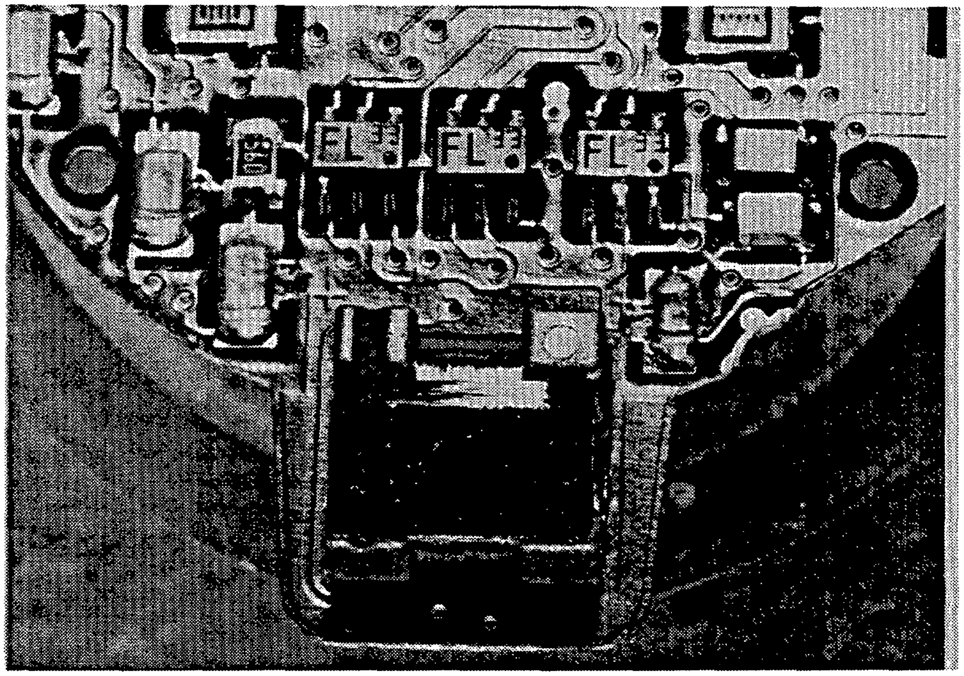


Figure 6. Closeup of flux-gate magnetometer.



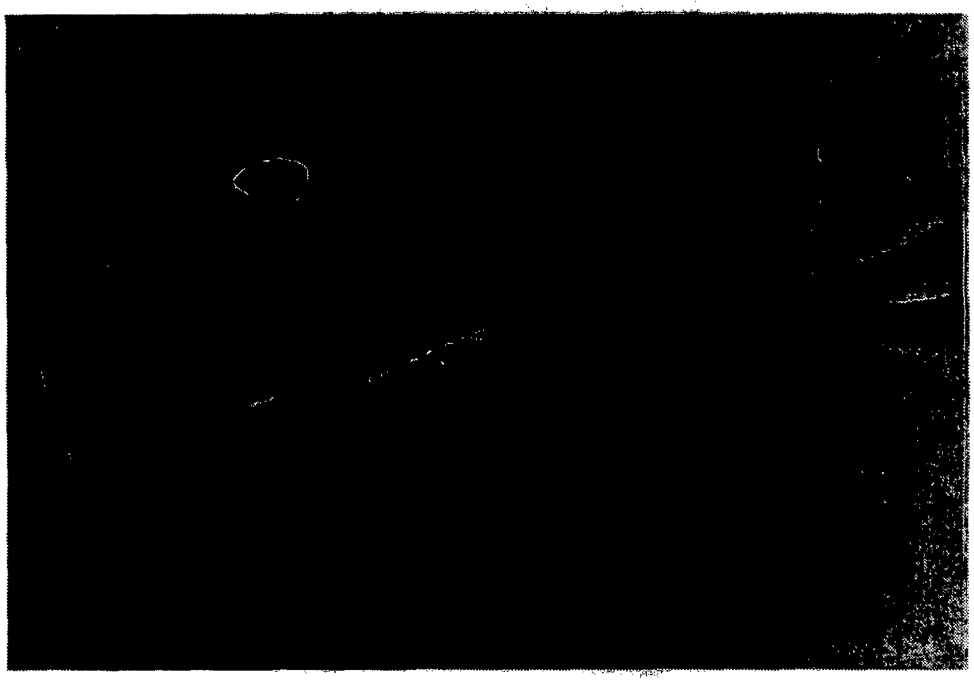
The electronic compass does have some problems in comparison with the lensatic compass. The electronic compasses evaluated generally weigh more and are bigger than the lensatic compass.[4] The battery requirements of the electronic compass could cause potential supply problems. In addition, the failure modes for NDI electronic compasses have not been studied and since the electronic compasses are more complex, they might have a higher rate of failure than the lensatic compass. Finally, the higher sensitivity of the electronic compass can cause problems for soldiers using the compass while moving, since the compass must be kept still while being read.

3. Compasses Studied

For this study, we tested three different electronic compasses. The first is the KVH DataScope (see fig. 7). This compass consists of a 5 × 30 monocular used for sighting, a flux-gate sensor, and associated electronics. This compass differs from the present lensatic compass in the way that it obtains sights. The lensatic compass uses a thin-line sight to target an object. The compass coordinate is then read using a magnifying eyepiece. The coordinates can be obtained in degrees or mils, depending on need. To obtain a reading with the DataScope, the unit is first turned on and, if necessary, calibrated. This calibration is normally only required after battery replacement. The user sights through the 5 × 30 monocular, and the bearing is displayed in the monocular using an LCD display. This compass does allow for both mils and degree readings, and can store up to 10 different

[4] *Final Report of the Hand Held Digital Compass Demonstration and Evaluation, Countersurveillance, Deception, and Topographic Division, Combat Engineering Directorate, U.S. Army Belvoir Research, Development and Engineering Center, May 1992.*

Figure 7. KVH DataScope.



bearings. It also has the ability to store chronometer readings with the bearings, thus allowing speed calculations to be performed. One other feature of this compass is the built-in rangefinder that uses known heights and relative size to find the range of an object.

The second compass studied was the KVH C-100 (see fig. 8) compass engine. This compass uses most of the electronics package employed in the KVH DataScope. The system is plugged into a personal computer and the data are read from the computer screen. There are two different versions of this compass system available. The first uses the DataScope's flux-gate sensor, which allows 16 degrees of tilt, while the other has a gimbaled flux-gate sensor, which allows 45 degrees of tilt. All of the KVH compasses are accurate to 0.5 degrees, with a repeatability of ±0.2 degrees. Since the KVH C-100's electronics are identical to the DataScope's, all testing was done with the DataScope. The last compass considered for this program was a compass built into a watch sold by Casio. This compass did not meet the Army's requirements, since it was only accurate to ±25 degrees, and so it was not tested.

4. Experimental Results

Several experiments were run on the KVH DataScope to study its operational range. The first study, documented in table 1, shows the repeatability of the compass readings. Table 2 shows how nearby metal objects influenced the DataScope and the lensatic compass. Table 3 is a comparison of the DataScope with the lensatic when the two compasses are tilted at varying angles from the horizontal.

The data in table 1 were obtained by mounting the compass on a tripod and sighting on different objects at various points on the compass. Each

Figure 8. KVH C-100 compass engine.

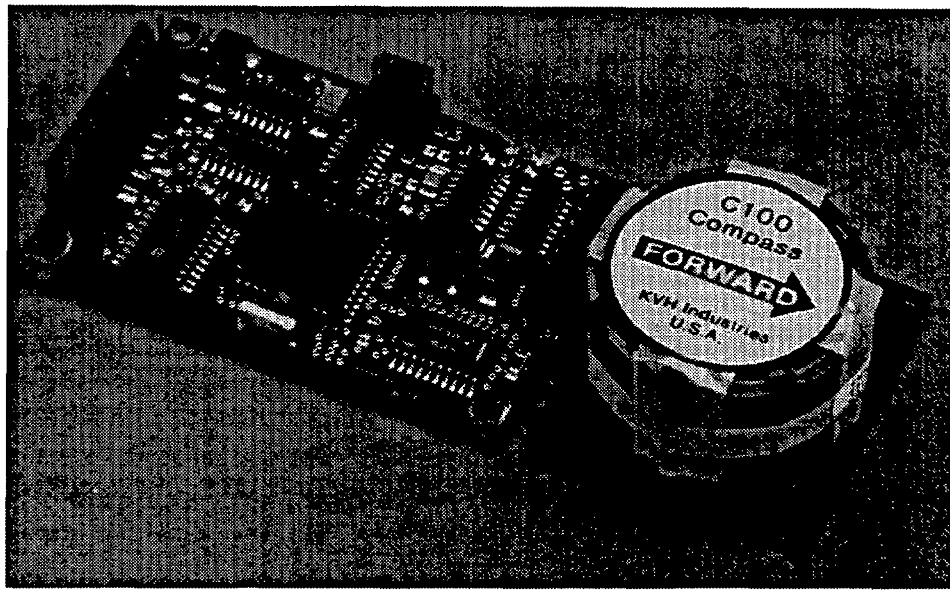


Table 1. KVH repeatability data.*

Run 1 (deg)	Run 2 (deg)	Run 3 (deg)	Run 4 (deg)	Run 5 (deg)	Run 6 (deg)	Run 7 (deg)	Run 8 (deg)	Average (deg)	Standard deviation (deg)	Maximum (deg)	Minimum (deg)
158.3	158.6	158.6	158.7	158.8	158.4	158.0	158.2	158.45	0.27	158.8	158.0
216.9	217.2	217.1	217.0	216.8	217.6	217.5	217.6	217.21	0.32	217.6	216.8
273.0	273.0	273.7	273.1	273.5	274.2	274.2	274.1	273.60	0.53	274.2	273.0
329.1	329.2	330.0	329.2	330.0	330.2	330.1	330.4	329.78	0.52	330.4	329.1
5.2	5.2	5.0	4.3	5.0	4.9	5.0	5.0	4.95	0.28	5.2	4.3
50.5	50.3	50.2	49.8	49.7	49.6	49.4	49.5	49.88	0.41	40.5	49.4
97.9	98.1	97.8	98.5	96.5	96.4	96.5	96.7	97.30	0.86	98.5	96.4
145.6	145.7	145.8	145.5	145.0	145.2	145.0	145.2	145.38	0.32	145.8	145.0

*Calibration 7

Table 2. Influence data.

Distance from fence (ft)	KVH DataScope (deg)	Standard lensatic (deg)
15.0	153.7	153.6
10.0	153.7	153.6
5.0	154.7	153.6
3.0	159.7	156.9
0.5	186.7	177.2
Standard deviation	14.20	10.29

object bearing was measured eight times by orientating from object to object. This test was done in an area where the compass could be easily calibrated to remove any external influences on the data. The DataScope can be recalibrated at any time by putting the compass into its calibration mode. In this mode, the DataScope asks the user to aim the scope at eight different points. At each point the compass must be held steady for 15 s. Once all eight points have been sighted, the compass indicates the accu-

Table 3. Tilt data.

	Lensatic			DataScope	
(deg)	*x-z* bearing (deg)	*y-z* bearing (deg)	(deg)	*x-z* bearing (deg)	*y-z* bearing (deg)
0.0	155.8	69.8	0.0	158.4	244.8
5.0	155.8	69.8	5.0	158.3	244.7
10.0	155.8	68.6	10.0	158.3	243.9
15.0	Mechanical limit reached		15.0	157.6	243.9
20.0			20.0	157.8	242.2
25.0			25.0	157.6	242.2
30.0			30.0	150.6	234.3
Standard deviation	0.00	0.65	Standard deviation	0.37	1.16

racy of the calibration by displaying a number between 1 and 10. Any calibration greater than 6 is considered a good calibration by the compass. As the calibration confidence number increases, so does the accuracy. The whole process takes approximately two minutes. For the data contained in table 1, the calibration confidence number was 7 out of 10. The data in table 1 indicate that for most of the bearings, the DataScope was accurate to within 1 degree or less. Some of the error in these values is caused by the distance from the object to the compass or the size of the object. Very thin objects or very distant objects made it difficult to keep the compass cross-hair accurately aligned to the object.

The data in table 2 show how the electronic compass compares to the standard-issue compass when both compasses are brought into close proximity with metal objects. A standard chain link fence served as the metal object. A reference point was chosen on which to sight both compasses. Bearing measurements from both compasses were taken as the compasses were moved closer to the metal fence. These data demonstrated that the standard compass is less affected by nearby metallic objects. The electronic compass was affected up to 5 ft from the metallic object, while the lensatic compass was not affected until 3.5 ft. It is possible to recalibrate the DataScope to work in areas where there are large concentrations of metal objects, but this calibration must be redone if the compass is moved from the area.

After all of the experiments were run, we compared the DataScope and the lensatic (see table 3). The DataScope is much more accurate in taking a bearing than the lensatic compass. The lensatic compass is only accurate to 1.0 degrees, while the DataScope is accurate to 0.5 degrees with 0.1 readout accuracy. The DataScope is also more accurate when tilted. The lensatic compass could not be tilted more then 10 degrees because the compass wheel would contact the top glass and would not rotate. The DataScope could be tilted to 25 degrees before the readings were thrown off by more then 1 degree. The DataScope's reading made it very clear when it had been tilted past 25 degrees or when the bearing changed by more then 10 degrees. However, the lensatic compass performed much better than the

DataScope when brought into close proximity with metal without recalibration. The DataScope was affected at distances less than 5 ft, while the Lensatic was not affected until it was less than 3.5 ft from the object.

Next, we tested how these compasses performed when operated near a running vehicle. The vehicle used to perform this test was a late-model truck that uses extensive computer control to manage the fuel system. This type of computer-control system is becoming more common as mileage, emission, and power requirements increase. These computer systems and high-energy ignition systems create electrical and magnetic fields that can affect the accuracy of a compass. To compare the two compasses, a tripod was set up 25 ft in front of the vehicle. Each compass was mounted on the tripod and a bearing was taken. The vehicle was then started and the same object was used to take a second bearing. This routine was repeated at distances of 5 ft from the vehicle and with the tripod mounted in the bed of the vehicle. Table 4 shows the results from this test. At both 25 and 5 ft, the bearings did not change when the vehicle was started. The bearings did change when the tripod was mounted in the bed of the vehicle, which could be caused by the metal content of the vehicle. When the measurements were taken from the bed, the values did not change when the vehicle was started. To make sure that the DataScope was giving accurate data, it was recalibrated while in the bed and new readings were taken. These readings did not differ from the previous readings. It was noted that while the vehicle was running, the DataScope's readout did bounce over a 1 degrees range. This could have been caused by the vibrations of the running vehicle or it could have been caused by electromagnetic interference. When data were taken from inside the passenger compartment (see table 5), the values changed from the baseline value. When the vehicle was started the values changed by more then 10 degrees, causing inaccurate readings. It is possible to recalibrate the DataScope so that it reads correctly when the engine is running, but it would have to be recalibrated if measurements were made with the engine off.

Table 4. Vehicle data.

	Lensatic			Datascope		
	25 ft (deg)	5 ft (deg)	In vehicle (deg)	25 ft (deg)	5 ft (deg)	In vehicle (deg)
Baseline	87.2	90.0	69.8	85.2	89.6	70.8
Vehicle running	87.2	90.1	69.8	85.2	90.7	71.3
Recalibration	—	—	—	—	—	69.8
Standard deviation	0.00	0.07	0.00	0.00	0.78	0.76

Table 5. Vehicle data inside passenger compartment.

	Lensatic (deg)	Datascope (deg)
Baseline	340.3	339.4
Vehicle running	349.9	350.6
Vehicle running	350.4	350.9
Standard deviation	5.69	6.55

5. Conclusion

The data obtained from these experiments showed that the electronic compass was more accurate in some circumstances and less accurate in others. The DataScope was within 1 degree of heading repeatability over eight different values taken at eight different times. Since the lensatic's face is only marked off in increments of 5 degree, its accuracy is good only to about 2 degrees. The area where the lensatic performs well is near metal objects. The DataScope had a higher deviation when tilted than the lensatic did, but this can be attributed to the DataScope's more accurate readout. The DataScope did allow higher levels of tilt before deviating by more than 1 degrees out of specifications. Studies done around electromagnetic fields indicate that both compasses are equally affected. The big problem with the DataScope and other electronic compasses is their output sensitivity. Most of the electronic compasses investigated had displays that would read out at 0.1 degrees. This caused the readout to jump around considerably, making it difficult to obtain a reading, especially inside a moving vehicle or where there was a lot of interference. Several of the manufacturers indicated that the readouts can be made less sensitive.

There are other areas that need to be addressed before the lensatic can be replaced by an electronic compass. More work will have to be done to make sure that the electronic compass is not adversely affected by ionizing and electromagnetic radiation generated by other systems. These compasses will also need to be tested for susceptibility to chemical and biological warfare agents and for ease of decontamination. The DataScope appeared to have some features that could make decontamination a problem: the buttons that might absorb the agent, or areas around the buttons maybe hard to clean. Other areas that will require further testing are the electromagnetic pulse and radiation hardness of these devices. Finally, the ability of these compasses to survive the hard use that the average soldier will put them through must be thoroughly studied.

In conclusion, the preliminary studies done on these electronic compasses indicate that they generally meet or exceed the lensatic in both functionality and accuracy. They fall short of the lensatic in ease of use, and they might not be as rugged as the lensatic compass. However, the Army has tested several electronic compasses in the field[4] and found most of them to be as rugged as the lensatic. Most importantly, use of back-lit LCDs eliminates the need to use tritium to allow nighttime operation. The resulting savings in disposal costs should more than compensate for any developmental costs to field an electronic compass for the Army.

[4]*Final Report of the Hand Held Digital Compass Demonstration and Evaluation, Countersurveillance, Deception, and Topographic Division, Combat Engineering Directorate, U.S. Army Belvoir Research, Development and Engineering Center, May 1992.*

Distribution

Admnstr
Defns Techl Info Ctr
Attn DTIC-DDA (2 copies)
Cameron Sta Bldg 5
Alexandria VA 22304-6145

Director
Defns Nuc Agcy
Attn RAEE L Cohn
Attn RAEE L Palkuti
6801 Telegraph Rd
Alexandria VA 22310-3398

Hdqrts US Army Spc Oprn Cmnd
Attn A Gies
Attn DCS-FCI-CD-TB S Raineri
Attn E Blough
Bldg D3206 Rm 503
FT Bragg NC 28307-5200

US Army Corps of Engrg
Attn CEHND-SY R Johnson
Attn GEHND-SY J Loyd
PO Box 1600
Huntsville AL 35807-4301

Director
US Army Sp & Strtgc Defns Cmnd
Attn CSSD-SD-AM A Corder
Attn CSSD-SD-AM A Kuehl
Attn CSSD-SD-AM G Little
Attn CSSD-SD-AM K Blankenship
Attn CSSD-SD-AM P Adams
Attn CSSD-SD-AM C Harper
Attn CSSD-SA-ES R Goodman
Attn CSSD-SA-EV R Bradshaw
PO Box 1500
Huntsville AL 35807-3801

Commander
US Army White Sands Missile Range
Attn STEWS-NE J Meason
White Sands Missile Range NM 88002-5180

Commanding Officer
Nav Rsrch Lab
Attn C. Dozier
Attn Code 6816 W Jenkins
Attn Code 8120 A. Fox
4555 Overlook Ave SW
Washington DC 20375-5000

Director
Nav Rsrch Lab
Attn Code 2620 Tech Lib Br
Washington DC 20375

Commander
Nav Surfc Weapons Ctr
Attn Code WA501 Navy Nuc Prgms Ofc
Attn Code WA52
Attn E-43 Tech Lib
Attn WA50
White Oak MD 20910

Commander
Nav Surfc Weapons Ctr
Attn Code WR Rsrch & Techlgy Dept
Attn DX-21 Lib Div
Dahlgren Lab
Dahlgren VA 22448

Nav Weapons Spprt Ctr
Attn Code 6054 T Turflinger
Bldg 2088
Crane IN 47522

USAF Sp & Mis Sys Ctr
Attn K Basany/MTFS
2400 E. El Segundo Blvd
Los Angeles CA 90009-2960

Booz-Allen & Hamilton, Inc
Attn J Terrell
8283 Greensboro Dr
McLean VA 22102

Hughes STX Corp
Attn D Manion
7701 Greenbelt Rd Ste 400
Greenbelt MD 20770

Project Development & Radiation Rsrch Office
Attn R Bhatt
10115 DuPortail Rd Ste 136
FT Belvoir VA 22060-5847

NASA Langley Rsrch Ctr
Attn AMSRL-VS W Elber
Hampton VA 23681-0001

Distribution

US Army Rsrch Lab
Attn AMSRL-SL-CS J Beilfuss
Attn AMSRL-SL-CS M Bumbaugh
Attn AMSRL-SL-CS T Flory
Attn AMSRL-WT-NB D Davis
Edgewood MD 21010-5423

US Army Rsrch Lab
Attn AMSRL-MA L W Johnson
Arsenal Stret
Watertown MA 02172-0001

US Army Rsrch Lab
Attn AMSRL-EP C Thornton
Attn AMSRL-EP-P R Hamlen
Attn AMSRL-EP-PA H Christopher
Attn AMSRL-EP-PB S Gilman
Attn AMSRL-EP-PD G Guazzoni
Attn AMSRL-EP-T R Lauttman
FT Monmouth NJ 07703-5601

US Army Rsrch Lab
Attn AMSRL-WT-PC A Barrows
Aberdeen Proving Ground MD 21005-5066

US Army Rsrch Lab
Attn AMSRL-OP-AP-L Lib (3 copies)
Attn AMSRL-WT I May
Attn AMSRL-HR R L Keesee
Attn AMSRL-WT D Eccleshall
Attn AMSRL-WT G Klem
Attn AMSRL-WT J Frasier
Attn AMSRL-WT-NC R Lottero
Attn AMSRL-WT-T W Morrison
Attn AMSRL-WT-W C Murphy
Attn AMSRL-WT-WB W P D'Amico
Attn AMSRL-WT-WD A Niiler
Attn AMSRL-WT-WG L J Puckett
Attn AMSRL-SL-NC J McCullen
Attn AMSRL-CI W H Mermagen Sr
Aberdeen Proving Ground MD 21005-5425

US Army Rsrch Lab
Attn AMSRL-VP R Bill
21000 Brookpark Rd
Cleveland OH 44135-3191

US Army Rsrch Lab
Attn AMSRL-BE-A D R Veazey
Attn AMSRL-SL J Wade
Attn AMSRL-BE COL R Evans
White Sands Missile Range NM 88002-55

US ARDEC
Attn AMSTA-AR-AEF-M R Goodman
Adelphi MD 20783-1197

US Army Rsrch Lab
Attn AMSRL-CP B Fonoroff
Attn AMSRL-CP COL J Correia
Attn AMSRL-CP-C D Snider
Attn AMSRL-CP-CC J Predham
Attn AMSRL-CP-CD A Stewart
Attn AMSRL-CP-CD S Karamchetty
Attn AMSRL-EP-EC A Goldberg
Attn AMSRL-OP-SD-PM A Lee
Attn AMSRL-OP-SD-TA Mail & Records Mgmt
Attn AMSRL-OP-SD-TL Tech Library (3 copies)
Attn AMSRL-OP-SD-TP Tech Pub
Attn AMSRL-PS-AA G Simonis
Attn AMSRL-SE J Pellegrino
Attn AMSRL-SE-EO N Gupta
Attn AMSRL-SE-EO T Tayag
Attn AMSRL-SE-RU H Brann
Attn AMSRL-SL-CE A Bevec
Attn AMSRL-SL-CE D Manyak
Attn AMSRL-SL-CE G W Still
Attn AMSRL-SL-N M Miller
Attn AMSRL-SS V DeMonte
Attn AMSRL-SS-IB M Patterson
Attn AMSRL-SS-IC P Emmerman
Attn AMSRL-WT-L R Weinraub
Attn AMSRL-WT-N J Halpin
Attn AMSRL-WT-N J Ingram
Attn AMSRL-WT-N J McGarrity
Attn AMSRL-WT-NA R A Kehs
Attn AMSRL-WT-NB H Brandt
Attn AMSRL-WT-NB J Gwaltney
Attn AMSRL-WT-NB M Abe
Attn AMSRL-WT-ND J R Miletta

Distribution

US Army Rsrch Lab
Attn AMSRL-WT-NF C Fazi
Attn AMSRL-WT-NF L Jasper
Attn AMSRL-WT-NF S Saddow
Attn AMSRL-WT-NG A Abou-Auf
Attn AMSRL-WT-NG A J Lelis
Attn AMSRL-WT-NG B Geil (15 copies)
Attn AMSRL-WT-NG B J Rod
Attn AMSRL-WT-NG B Lilley
Attn AMSRL-WT-NG B McLean
Attn AMSRL-WT-NG C Scozzie
Attn AMSRL-WT-NG D Robertson
Attn AMSRL-WT-NG G Ovrebo
Attn AMSRL-WT-NG H Boesch
Attn AMSRL-WT-NG J Benedetto
Attn AMSRL-WT-NG K W Bennett

US Army Rsrch Lab
Attn AMSRL-WT-NG J Blackburn
Attn AMSRL-WT-NG J Vanderwall
Attn AMSRL-WT-NG M DeLancey
Attn AMSRL-WT-NG R B Reams
Attn AMSRL-WT-NG R Moore
Attn AMSRL-WT-NG T Griffin
Attn AMSRL-WT-NG T Mermagen
Attn AMSRL-WT-NG T Oldham
Attn AMSRL-WT-NG T Taylor
Attn AMSRL-WT-NG W Tipton
Attn AMSRL-WT-NH D Conrad
Attn AMSRL-WT-NH G Huttlin
Attn AMSRL-WT-NH J Corrigan
Adelphi MD 20783-1197

Page Intentionally Blank